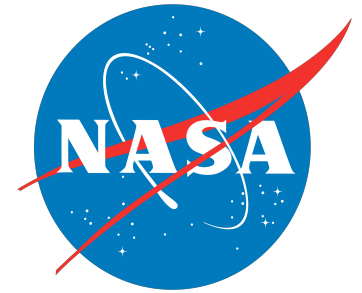


Onset of Flare Reconnection and Coronal Mass Ejection Acceleration in Eruptive Events

ABSTRACT NUMBER: SH23A-4150

Silvina E. Guidoni^{1,2}

silvina.e.guidoni@nasa.gov



Judy T. Karpen¹



C. Richard DeVore¹

Jiong Qiu³



¹ Space Weather Laboratory - NASA GSFC

² CUA, Institute for Astrophysics and
Computational Sciences

³ Solar Physics Group, Montana State
University-Bozeman

Abstract

The mechanism for producing fast coronal mass ejections/eruptive flares (CME/EFs) is hotly debated. Most models rely on ideal instability/loss of equilibrium or magnetic reconnection; these two categories of models predict different relationships between CMEs and flares. Discriminating between them requires continuous, high-resolution observations and state-of-the-art numerical simulations that enable the relative timing of key stages in the events to be determined. With the advent of SDO, STEREO, and massively parallel supercomputers, we are well poised to tackle this major challenge to our understanding of solar activity. In recent work (Karpen et al. 2012), we determined the timing and location of triggering mechanisms for the breakout initiation model (Antiochos et al. 1999), using ultra-high-resolution magnetohydrodynamic simulations with adaptive mesh refinement and high-cadence analysis. This approach enabled us to resolve as finely as possible the small scales of magnetic reconnection and island formation in the current sheets, within the global context of a large-scale solar eruption. We found that the explosive acceleration of the fast CME occurs only *after* the onset of rapid reconnection at the flare current sheet formed in the wake of the rising CME flux rope. In the present work, we discriminate between ideal and resistive mechanisms for fast CME/EFs using a combination of state-of-the-art observations and simulations. We compare flare reconnection rates, measured from flare ribbon UV brightenings observed by SDO/AIA and magnetograms from SDO/HMI, with the height evolution of CME fronts and cores, measured from STEREO/SECCHI EUV and coronagraph images. We also calculate these quantities from numerical simulations and compare them to observations, as a new test of the breakout initiation model.

Motivation

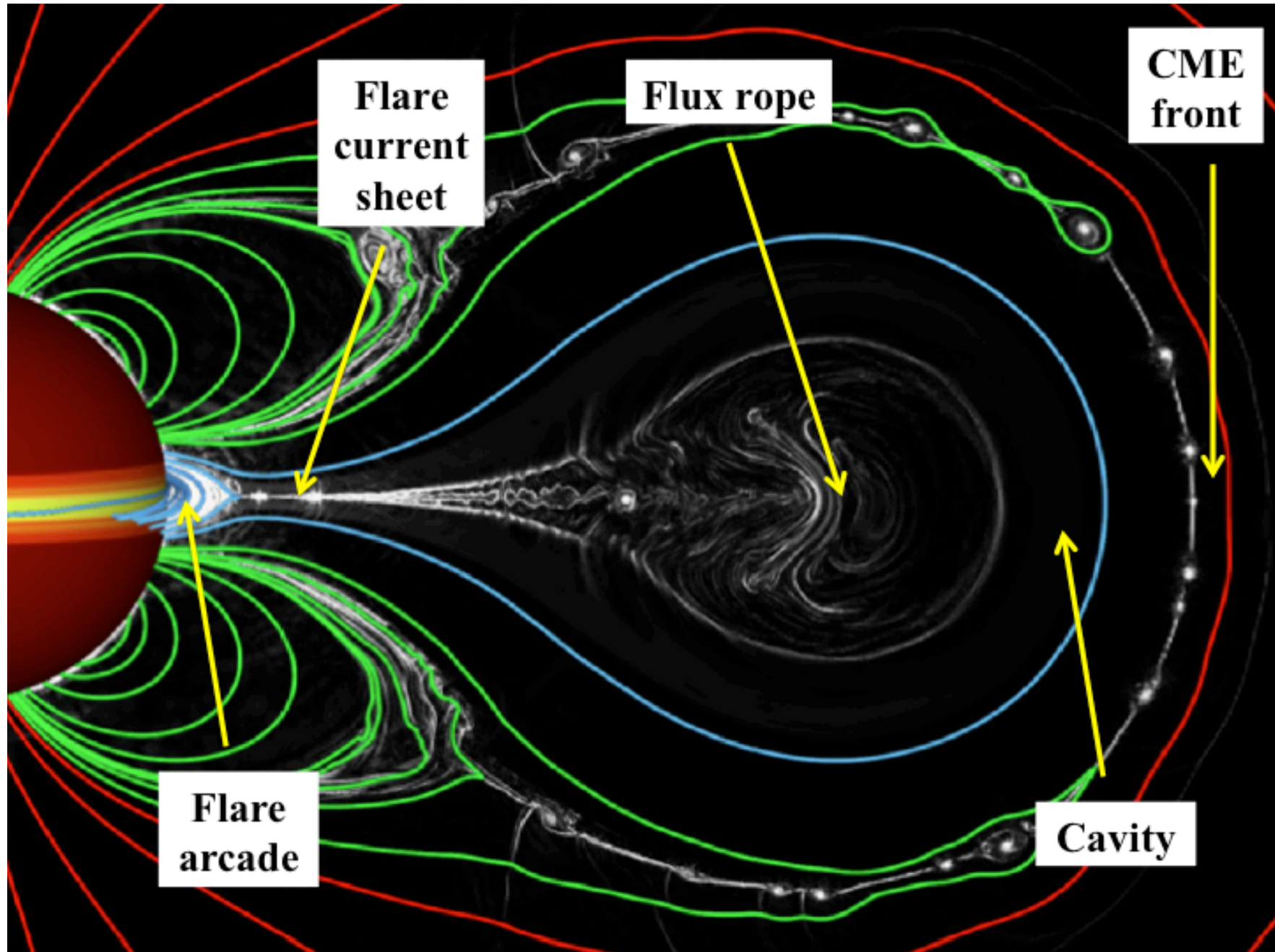
Is flare reconnection the driver of explosive solar eruptive events?

(1) Does flare reconnection onset precede fast CME take off in observed CME/EFs?

(2) Does flare reconnection precede CME take-off in simulations guided by observations?

(3) Are the simulated flare reconnection rates and CME acceleration profiles consistent with those derived from observations?

2.5D high resolution simulation



Methodology (1)

Observations:

Determine reconnected flux, $\Phi(t)$ for two-ribbon disk flares well observed by SDO.

Determine CME front and core height as function of time for flare associated CMEs well observed by STEREO/SECCHI.

Determine the time when the CME takes off and compare this time with the time profile of reconnection.

Methodology (2)

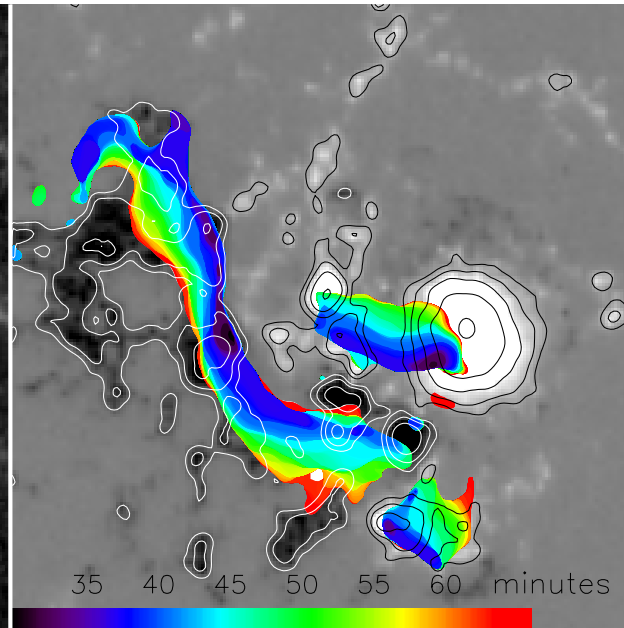
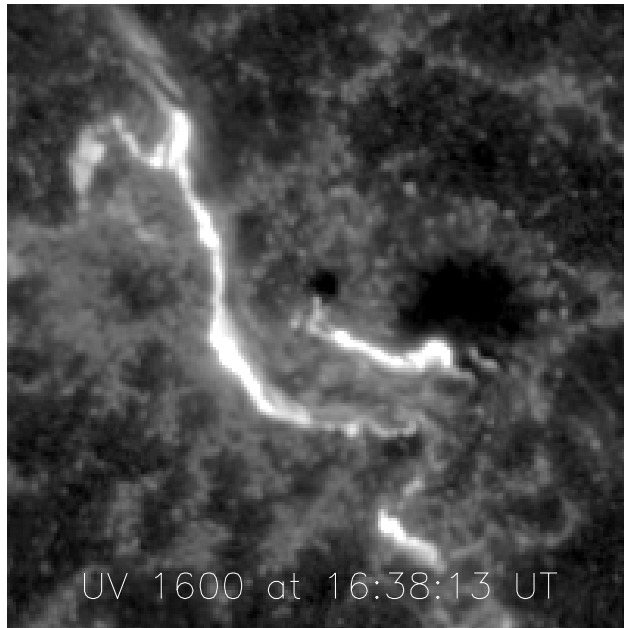
Simulations:

Perform 2.5D high-resolution global simulations of CME/EFs under the “breakout” scenario.

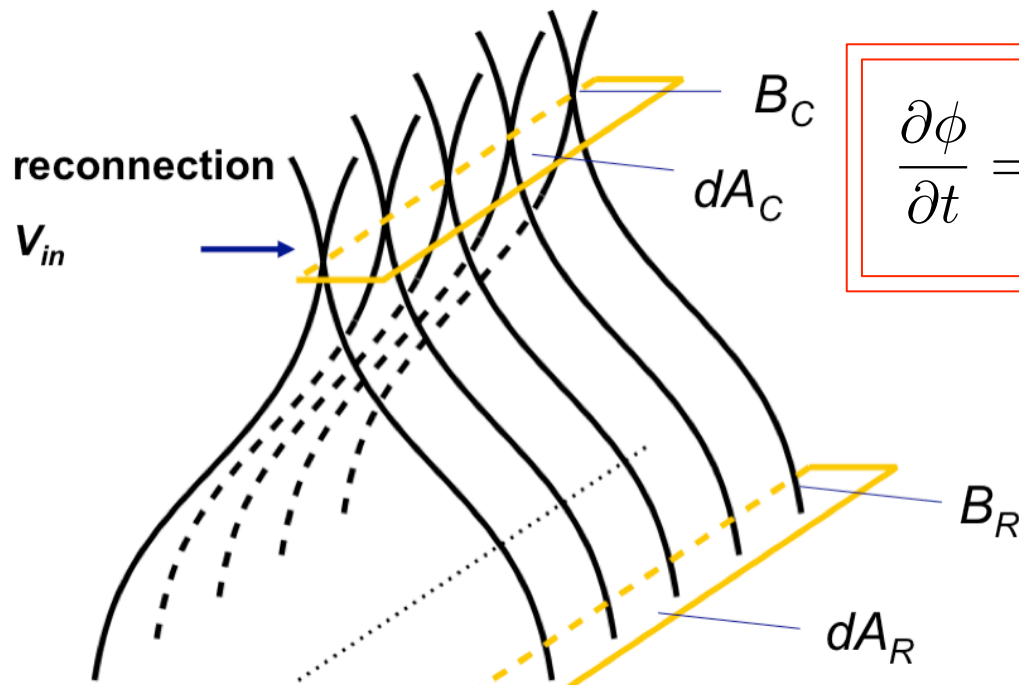
Determine reconnected flux, $\Phi(t)$.

Determine CME front and core height as function of time and compare them to the time profile of reconnection.

Observed reconnection flux



Energy from reconnection is rapidly deposited at the loops' footpoints, where dense plasma is heated, producing enhanced emission in optical and ultraviolet (UV) wavelengths. → Find dA_r

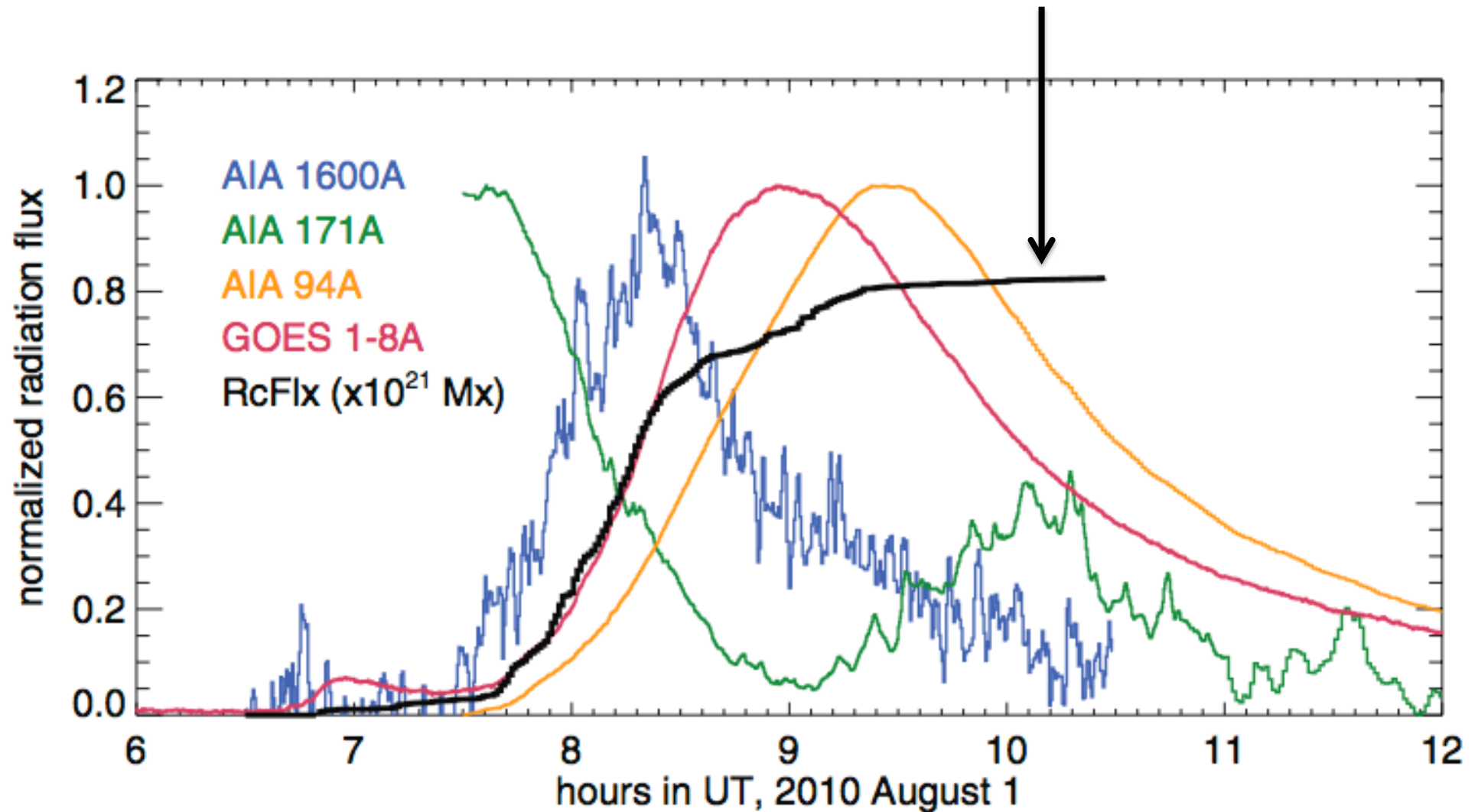


$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial t} \left(\int B_c dA_c \right) = \frac{\partial}{\partial t} \left(\int B_r dA_r \right)$$

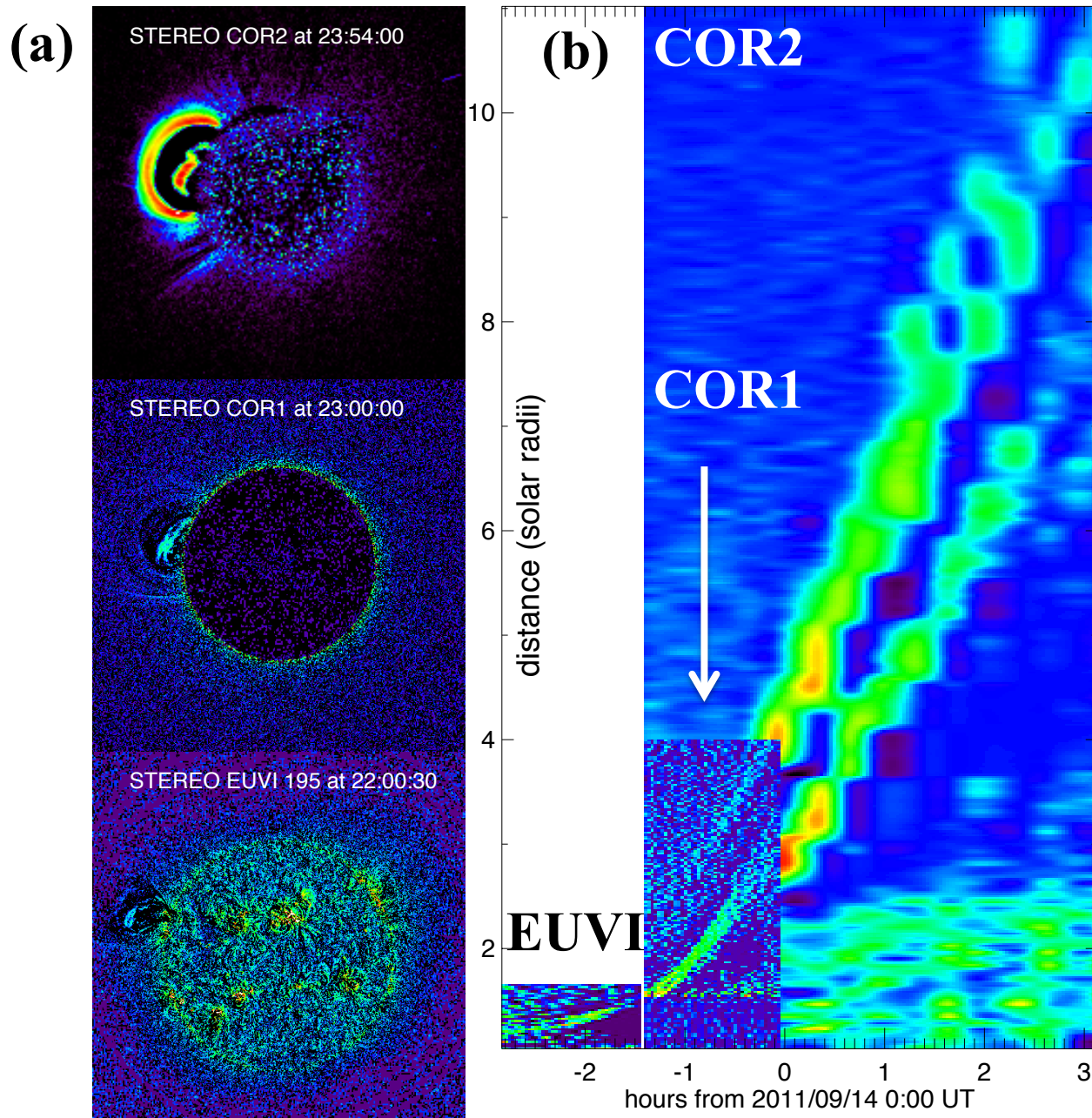
Bright ribbons are coaligned with magnetograms → Find B_r

Qiu et al. 2002, 2004, 2007, 2010, 2012

Example of observed reconnection flux



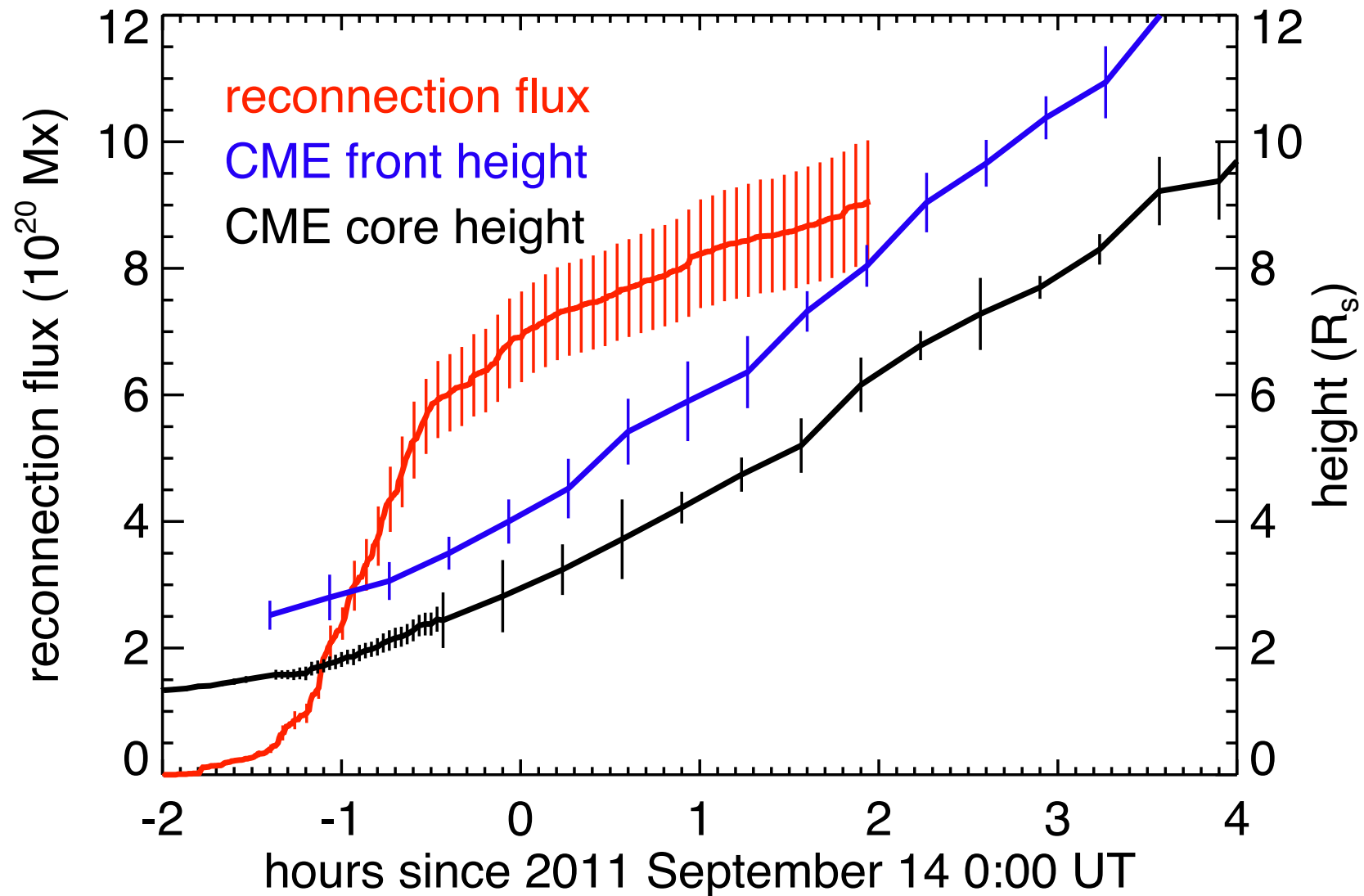
Observed CME core and front



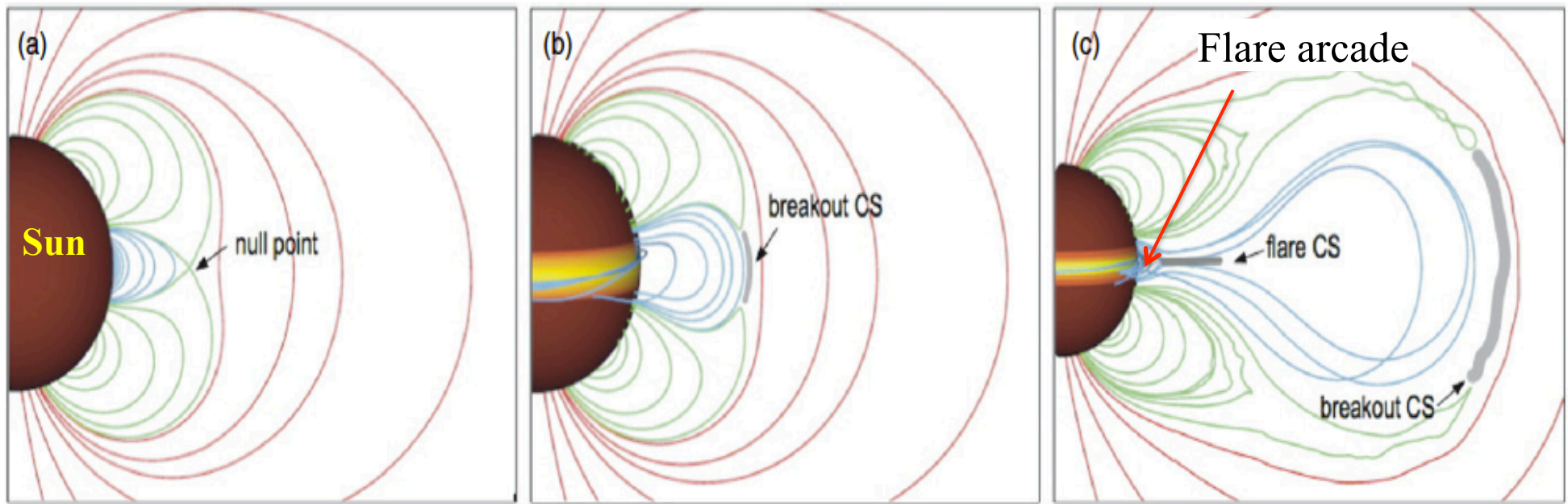
a) 13 Sept 2011 CME observed with COR2 (top), COR1 (middle), and EUVI (bottom).

b) distance vs. time stack plot showing CME core and front in EUVI, COR1, and COR2. Modified from Hu et al. (2014).

Reconnection onset precedes CME take-off?



Simulations: breakout model



Initial state: simple multipolar configuration.

Different colors indicate separate flux systems.

Longitudinal displacement of the field line footpoints in the central region of the core (blue field lines) adds free energy to the system.

Excess magnetic pressure in the core causes a current sheet (CS) to appear at the null (breakout CS).

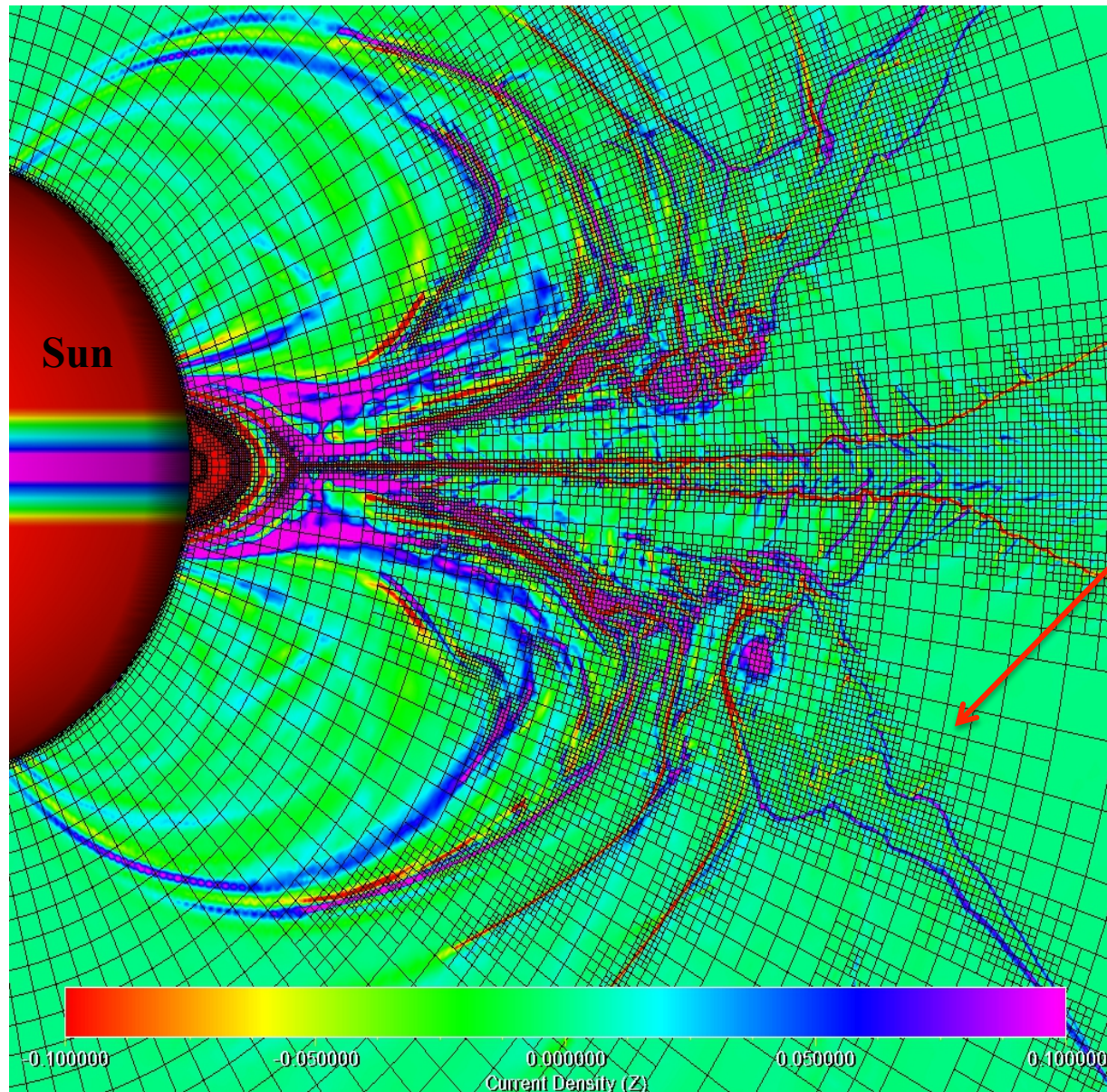
Outward expansion of the core forms the flare CS.

Fast reconnection at the flare CS creates the flare arcade.

Karpen et al., ApJ, 2012

Reconnection at the breakout CS removes overlying flux.

Adaptive mesh refinement

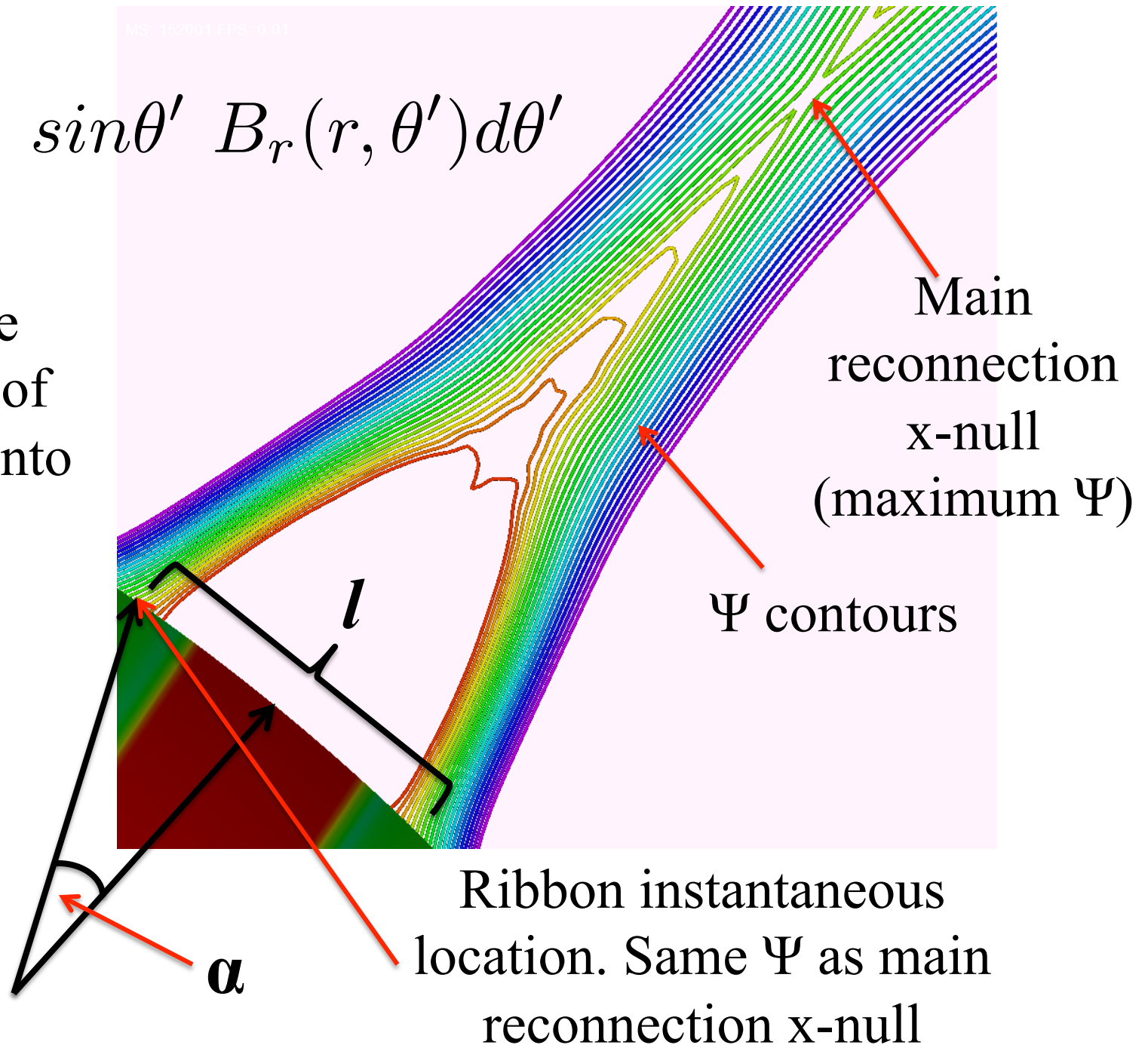


Ultra high-resolution (highest overall spatial resolution to date in an eruptive flare/CME simulation) is achieved through 8 levels of refinement.

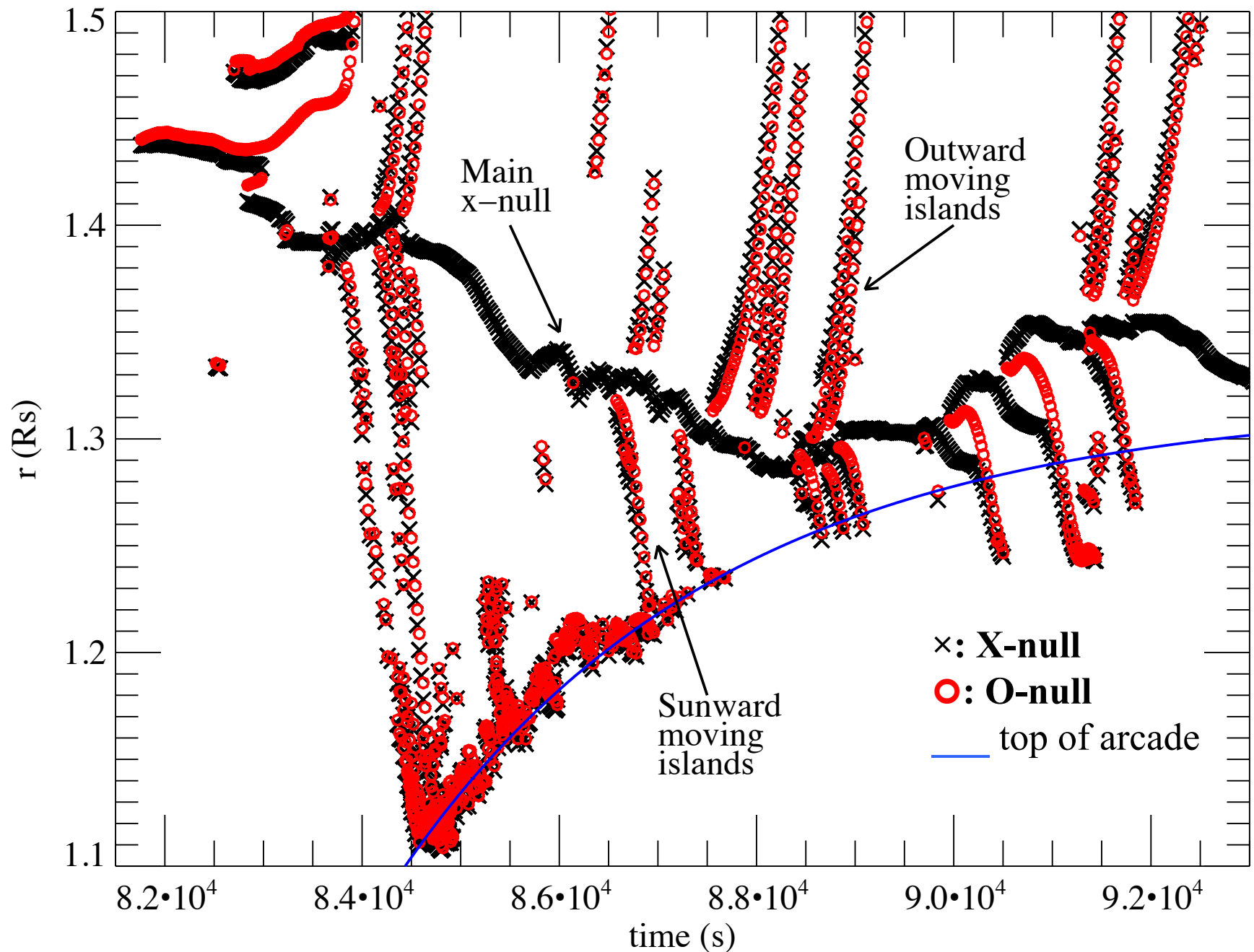
Poloidal Flux Function

$$\Psi = \int_0^\theta r^2 \sin\theta' B_r(r, \theta') d\theta'$$

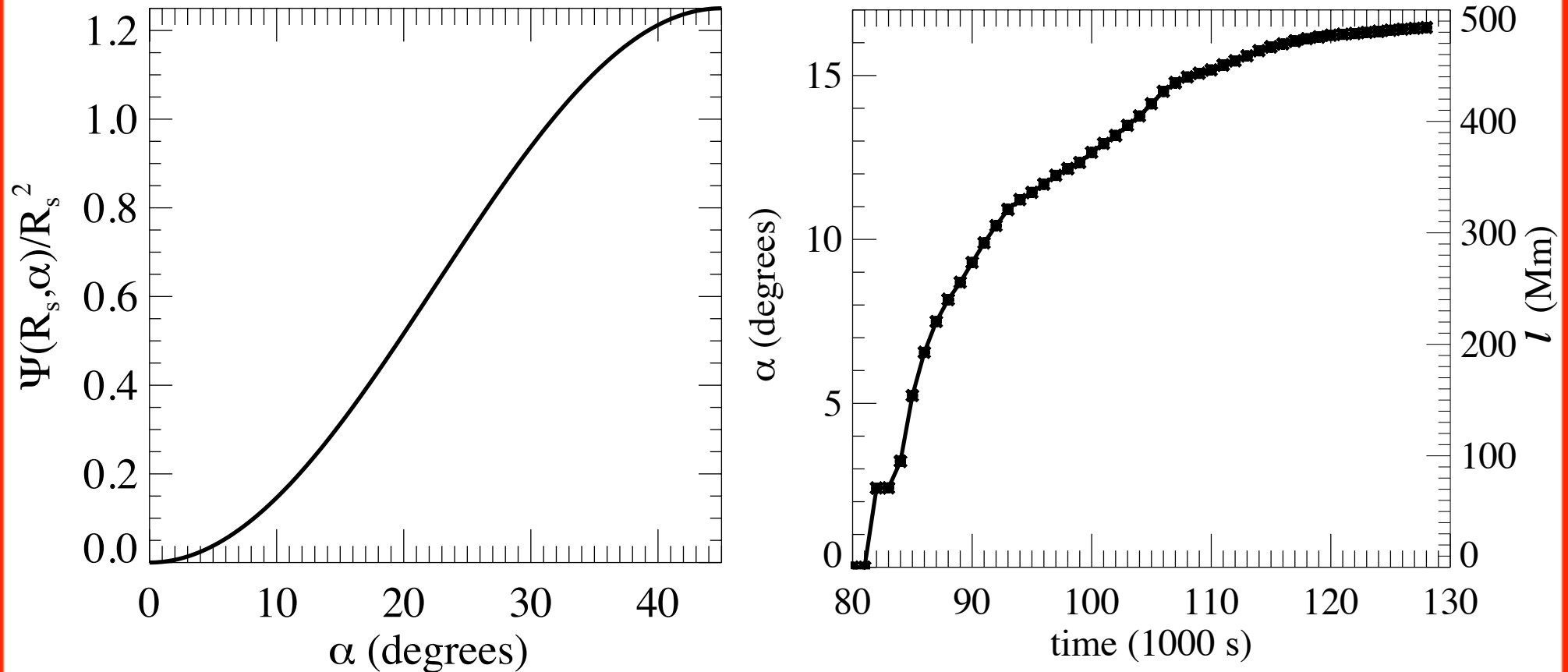
Traces the
projection of
field lines onto
plane



Null tracking in flare current sheet



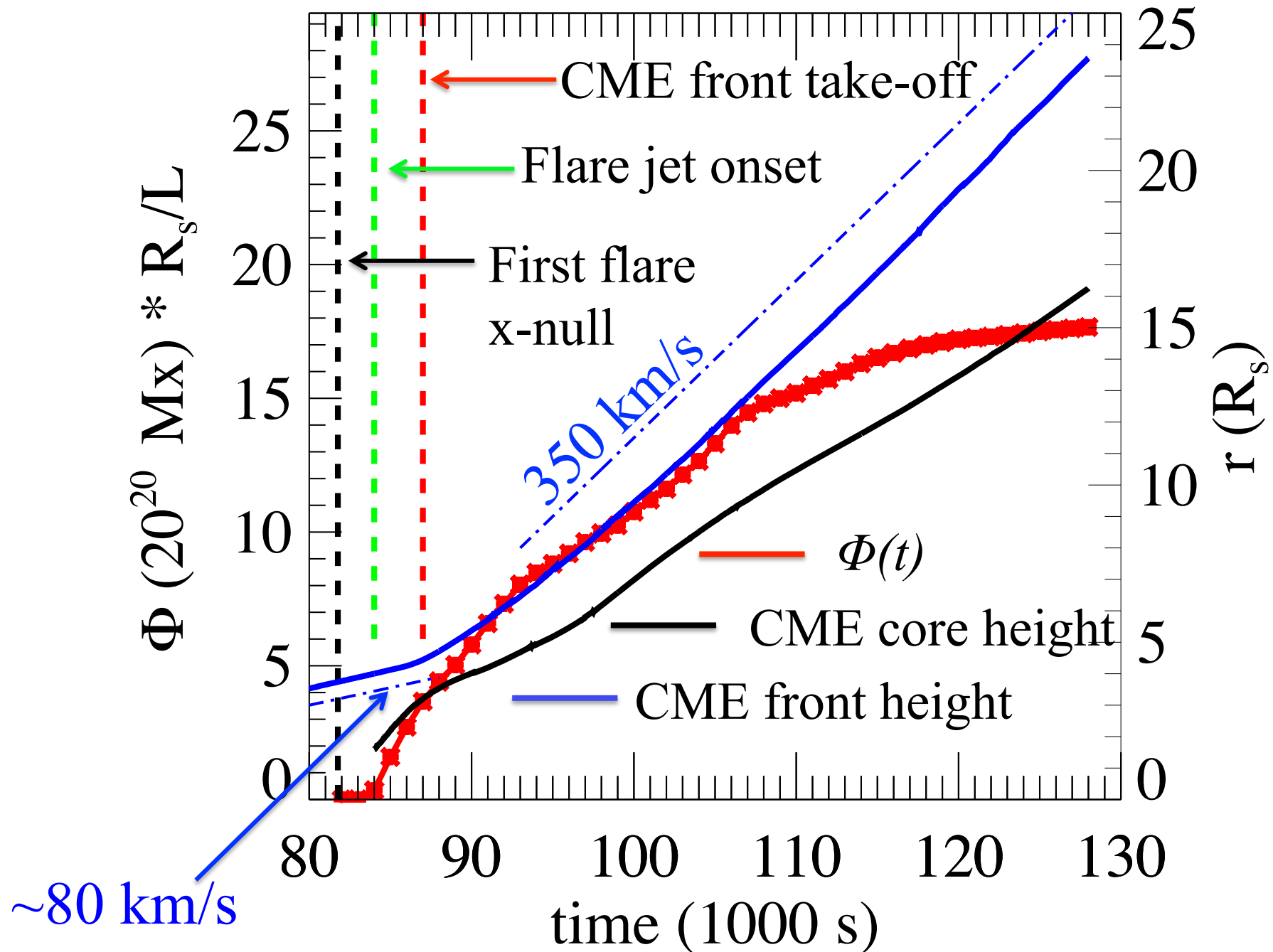
Ribbon location



Length of arcade axis

$$\Phi(t) = \frac{L}{R_s} \{ \Psi(R_s, \alpha(t)) - \Psi(R_s, \alpha(0)) \}$$

Simulation



Conclusions

- We can derive comparable diagnostics of reconnection from flare observations and simulations.
- Preliminary analysis of observations(?) and simulations seems to indicate that flare reconnection precedes fast CME take off in observed CME/EFs. This needs to be tested in more events and in more complex 3D simulations.
- We are making progress toward determining whether flare reconnection is the driver of explosive solar eruptive events.

Future work

- Study more events and more complex 3D simulations.
- Provide observational data to the community for testing other CME/EF models.

Thanks to Peter Wyper and Spiro Antiochos for helpful suggestions.

Sheared flare arcade

